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Protura, Pauropoda and Symphyla in Norwegian coniferous forest soils: abundance and vertical distribution

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Summary. Few studies exist on the quantitative occurrence of Protura, Pauropoda and Symphyla in Scandinavia. Soil samples were taken in spring and autumn in two coniferous forest sites near Oslo: one below and one above the marine limit. At each site, 7 different vegetation types were sampled, from poor pine forest to rich spruce forest. Protura occurred in all vegetation types, with maximum abundance in a *Vaccinium* pine forest (55 400 m^{-2}, corresponding to 63 % of the Collembola density). Pauropoda and Symphyla were found only in the site below the marine limit. Maximum abundance of Pauropoda (4 100 m^{-2}) was found in the richest soil, while Symphyla were most abundant (2 700 m^{-2}) in a *Vaccinium* pine forest. Pauropoda and Symphyla were absent in the two poorest pine forest soils. Protura were most abundant in the 0–3 cm layer in raw humus soils, but had a deeper maximum (most often 3–6 cm) in richer mull humus soils. Pauropoda and Symphyla occurred predominantly below 3 cm depth. All groups occurred down to 12 cm depth, but they can obviously go deeper. There were often considerable differences between spring and autumn densities of all three groups. It seems that the abundance of these groups may have a local character. Vegetation and soil types can only explain part of the variation in their abundance.

Key words: Protura, Pauropoda, Symphyla, coniferous forest, abundance, vertical distribution

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Introduction

Protura, Pauropoda and Symphyla have been studied very little in Scandinavian soils. Børset (1969) mentioned some records of Symphyla near Oslo and the known distribution of different Pauropoda species in Norway has recently been compiled by Scheller (in press). Quantitative data on these three groups in Norway are restricted to spruce forest on podzolic soil and Eu-Piceetum Myrtillus vegetation (Leinaas 1974, 1978). In other Scandinavian countries, Protura has been studied by Tuxen (1949), Huhta & Koskenniemi (1975), Gunnarsson (1980) and Persson et al. (1980). In Sweden, Pauropoda and Symphyla have been studied in agricultural soils (Andrén & Lagerlöf 1983; Lagerlöf & Scheller 1989). The present data were collected during a systematic study of the Collembola fauna in Norwegian coniferous forest soils (Hågvar 1982). In each of two sites, the whole gradient of soils was investigated, from

the poorest pine (*Pinus silvestris* L.) forest to the richest spruce (*Picea abies* (L.) Karst.) forest. In this study the data will only be presented at group level, since species identification remains to be completed.

Materials and Methods

A detailed description of habitats and sampling procedure has been given by Hågvar (1982), and only the main points will be mentioned here. Study area I was situated in Skrukkelia about 60 km north of Oslo, and area II near Ås, about 30 km south of Oslo. While area I was dominated by morainic deposits, area II often had a cover of marine sediments since it was was situated below the marine limit during the last glaciation.
In each study area, soil samples were taken during spring and autumn from seven different vegetation types. According to increasing fertility of the soil, these were:

1. Pine forest dominated by *Cladonia* lichens. Iron podzol, raw humus. Average depth of soil samples 4 cm.
2. Pine forest dominated by *Calluna vulgaris* (L.). Area I had an iron podzol with raw humus, and area II a shallow peat soil. Average sampling depth was 10 cm.
3. Mixed forest of pine, spruce and birch (*Betula pubescens* Ehrh.), with a field layer dominated by *Vaccinium* species. Iron podzol, raw humus. Mean sampling depth 10–12 cm.
4. Spruce forest dominated by *Vaccinium myrtillus* L. Iron podzol, raw humus. In area II it was also sampled in a site without a typical podzol profile (in the figures indicated by "-pod."). Sampling depth 12 cm, but only 6 cm in the podzol soil of area II.
5. Spruce forest with small ferns. Iron podzol with raw humus in area I, and brown earth with raw humus in area II. Average sampling depth was 10–12 cm.
6. Spruce forest with small herbs. Brown earth with a granular raw humus in area I, and a mull humus in area II. Sampling depth 12 cm, but only 9 cm in spring sample from area II.
7. Spruce forest with tall herbs. Brown earth with mull humus. An extra locality, with unusually rich soil, was sampled in area II, named "super" in the figures. This site was dominated by *Fraxinus excelsior* L. Mean sampling depth in the three sites was 11–12 cm.

At most samplings, 20 soil cores of 10 cm^2 were taken to a depth of 12 cm if possible. However, in area II, the "*Vaccinium myrtillus* podzol" site was sampled only during autumn, being limited to 9 cores, 6 cm in depth, and the spring sample in „small herbs" consisted of 11 cores, each covering 33 cm^2 with a depth of 9 cm. The lack of information from deeper levels in these two samplings is indicated by a minus in Fig. 3.

Results

Protura were recorded in all vegetation types and soil types and were missing only in the two pine forest habitats of Area I (Fig. 1). While the highest abundance in Area I was 6 300 m^{-2} (small ferns), Area II had densities of approximately 10 000 m^{-2} in several habitats with a maximum of 55 400 in a pine-dominated *Vaccinium* forest. This corresponds to 63 % of the Collembola density in the same site (Hågvar 1982). The *Vaccinium myrtillus* site with podzolic soil in area II also had a high abundance: 34 200 m^{-2}. This abundance is likely to be an underestimate as only the upper 6 cm of the soil were sampled.
At several sites, there were considerable differences in abundance between spring and autumn. In both study areas, there was a tendency to find the highest abundances of Protura in "medium rich" soil types, with lower numbers in both the very poor and the very rich soils.
Pauropoda and Symphyla were only recorded in area II (Fig. 2). Even here, they were absent in the two poorest soils. Abundance were never high and amounted to 4 100 m^{-2} in the richest "super" soil for Pauropoda, and to 2 700 m^{-2} in the *Vaccinium* forest for Symphyla. Both groups were found in most of the spruce forest sites, including both raw humus and mull humus soils. No clear preference for vegetation type or soil type could be found for these two

groups but they did avoid the poorest soils. As in Protura, the variation between spring and autumn abundance could be large.

The vertical distribution of all three groups is shown in Fig. 3. Only samples with at least 50 animals have been included. In raw humus soils, from *Calluna* to "small ferns", the highest abundance of Protura was usually found in the upper 3 cm. However, in the richer mull soils, the highest density was usually in the 3–6 cm layer, sometimes with considerable densities occurring even deeper. Obviously, Protura must occur deeper than 12 cm, especially in the "super" soil.

The only Pauropoda sampling with more than 50 individuals was in the "super" soil, showing a maximum at 6–9 cm depth. Also for Symphyla, only one sampling has been depicted, from *Vaccinium* vegetation, with highest abundance at 3–6 cm depth. Both groups seem to have a rather deep mean distribution. This impression was supported by the other samplings. Pauropoda and Symphyla were usually found down to 12 cm, with the main part of the population below 3 cm depth.

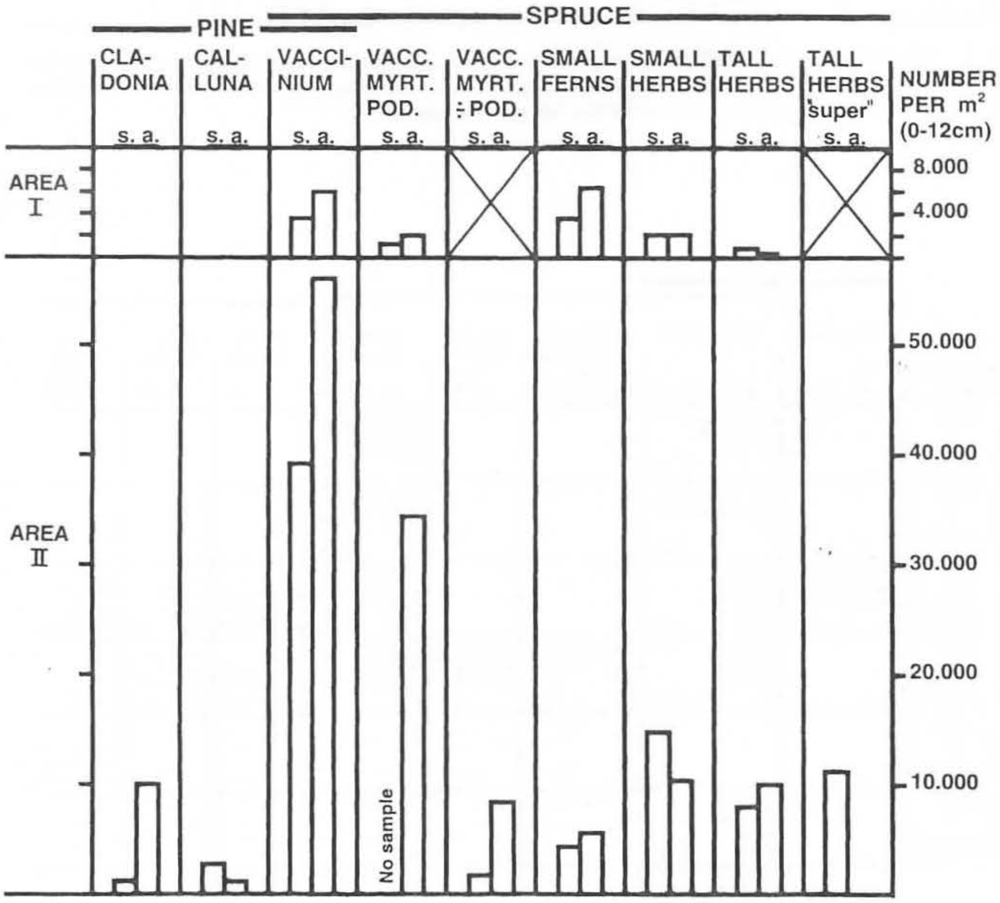

Fig. 1. Abundance of Protura within different plant communities in two study areas, from poor pine forest soils on the left, to rich spruce forest soils on the right. s. = spring sampling, and a. = autumn sampling. Two vegetation types in area I were not sampled. Further details of the vegetation and soil types are given in the text

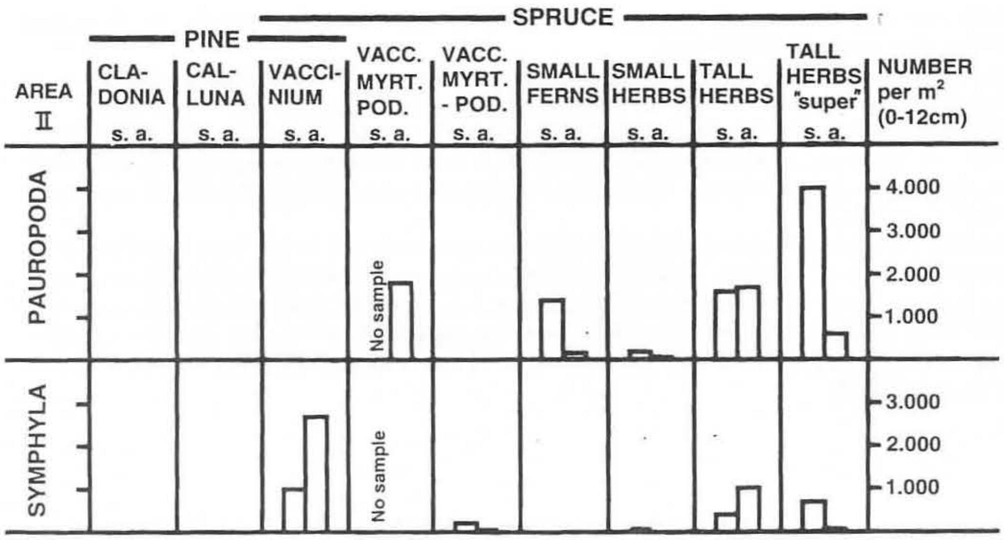

Fig. 2. Abundance of Pauropoda and Symphyla in different plant communities, from poor pine forest soils on the left, to rich spruce forest soils on the right. s. = spring sampling, and a. = autumn sampling. Further details of the vegetation and soil types are given in the text

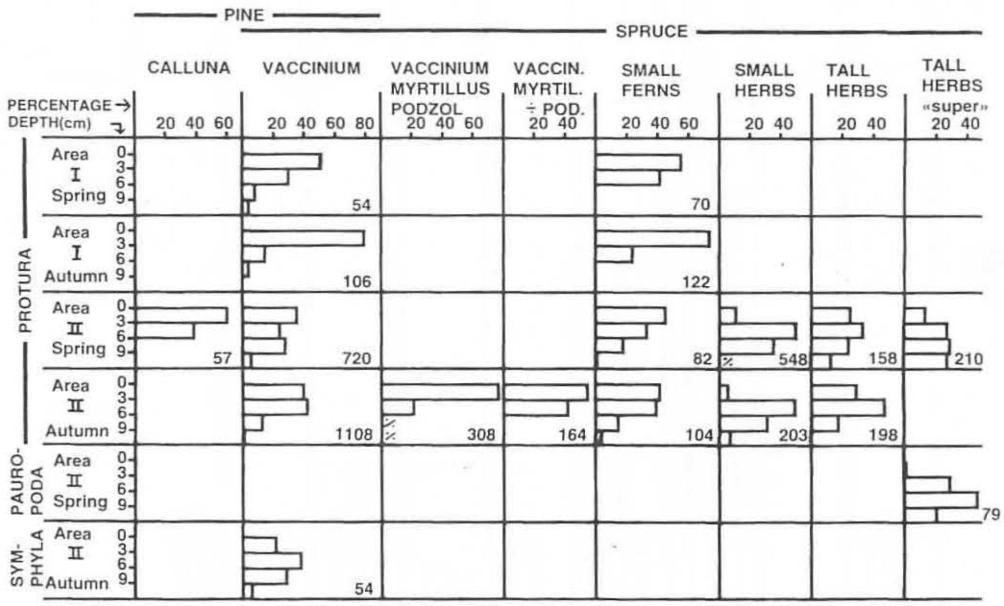

Fig. 3. Vertical distribution of Protura, Pauropoda and Symphyla in different plant communities, from poor pine forest soils on the left, to rich spruce forest soils on the right. Further details of vegetation and soil types are given in the text. Horizontal bars show the percentage of the population at different 3 cm depth levels. Only samples with at least 50 animals have been illustrated. Numbers within each box refer to the number of animals. A "minus" sign indicates that information is lacking

Discussion

Although the two study areas were only 90 km apart, they differed markedly with respect to the groups studied. Area I lacked both Pauropoda and Symphyla, and had lower densities of Protura. This may be due to a lack of marine sediments, perhaps combined with a colder climate (Hågvar 1982). None of the three groups showed any clear relationships with vegetation types, except for a tendency in Protura to be most numerous in "medium rich" soils. All groups have the following in common: they may occur in a wide range of humus types and soil profiles (from podzols to brown earths), their occurrence seems to have a local character, and it is difficult to predict their abundance. The differences in population size often observed between spring and autumn may partly be due to vertical migrations to and from layers below 12 cm depth. Further studies should include the deeper soil layers.

In three spruce forest sites with podzol soil at Nordmoen, 40 km north of Oslo, Hågvar (1984) found between 1000 and 2000 Protura m^{-2}. Other Scandinavian records in various forest types lie between 700 and 6500 m^{-2} (Tuxen 1949; Huhta & Koskenniemi 1975; Gunnarsson 1980; Persson et al. 1980). In winter samples from frozen soil, Leinaas (1978) found as many as 100000 Protura m^{-2} in a spruce forest of *Vaccinium myrtillus* type with podzolic soil, close to my corresponding sampling site in area II. He showed that 51 % of the Protura were killed by soil compression during ordinary sampling in non-frozen soil. This indicates that the present abundance values should be doubled. In that case, the abundance in the *Vaccinium* site of area II would surpass 100000 m^{-2} (Fig. 1).

The deep vertical distribution of Protura in brown earth soils with mull humus (Fig. 3) shows that these animals can penetrate into rather "compact" soil profiles, perhaps along roots or earthworm burrows.

Pauropoda have been reported from various soil types, including arable soils. The animals may occur deep in the soil and are often overlooked due to their small size (Edwards & Lofty 1969; Scheller 1974; Andrén & Lagerlöf 1983; Lagerlöf & Scheller 1989). Scheller (in press) has found a well established fauna in Norway with 13 species from 5 genera. Leinaas (1974) found 600 Pauropoda m^{-2} in *Vaccinium* spruce forest with podzol soil in area II. Similar densities were found in a pine forest in California (Starling 1944) and in a pasture soil by Salt et al. (1948). While the maximum density found in the present study was about 4 000 m^{-2} (Fig. 2), densities close to 18000 have been found in a ponderosa pine forest in California (Price 1973). According to Starling (1944) and Price (1973), Pauropoda are known to be quite common in coniferous forests in southern Europe and USA.

Studies of Pauropoda in Swedish agricultural soils revealed densities between 1100 and 1900 m^{-2}, with a seasonal maximum of 5000 (Lagerlöf & Scheller 1989). These abundances are comparable to many of the present findings (Fig. 2), and to those usually found in native soils of the temperate zone (Petersen & Luxton 1982), as well as from other Swedish agricultural soils (Andrén & Lagerlöf 1983).

Different Pauropoda species may have very different vertical distribution (Leinaas 1974). They may inhabit the litter layer as well as the mineral soil to great depth (Scheller 1974). In manipulated agricultural soil, Pauropoda are uniformly distributed throughout the soil profile (Lagerlöf & Scheller 1989).

Symphyla have been recorded in a number of soil types. They are able to inhabit deep layers and may migrate vertically in response to changes in humidity (Salt et al. 1948; Michelbacher 1949; Edwards 1958, 1959, 1961; Anglade 1967). From Norway, Børset (1969) reported some records in the Oslo area. In a monthly sampling program during one year in two Norwegian *Vaccinium* spruce forests with podzol soil, Leinaas (1974) found between 30 and 600 Symphyla m^{-2} in one site, and between 100 and 300 m^{-2} in the other. This corresponds well with the order of magnitude observed in most of the sites in the present study. The vertical distribution in the most abundant site showed high numbers down to 9 cm depth, with a maximum at 3–6 cm (Fig. 3). Symphyla are not restricted to the mineral soil, as assumed by Leinaas (1974).

In Swedish agricultural soils, Lagerlöf & Scheller (1989) found the Symphyla uniformly dis-

tributed throughout the soil profile, with mean abundances between 120 and 340 animals m^{-2}. This level of a few hundred animals m^{-2} agrees well with the Norwegian results, and even with other studies in native and agricultural soils (Petersen & Luxton 1982; Andrén & Lagerlöf 1983).

Edwards (1958) stated that dense populations of Symphyla were never found in soils which were too acid. However, in the present study, the highest abundance was found in a podzol with rather acid raw humus (pH 3.85 in the 0–3 cm layer and 3.62 in the 3–6 cm layer).

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